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Computational approaches to sustainable palm oil supply chain management: a systematic literature review of engineering and economic perspectives

Abstract

Palm oil supply chains are complex agro-industrial systems that integrate plantation management, harvesting, processing, logistics, and distribution. As these networks expand, researchers increasingly apply computational approaches to better understand supply chain operations and support analytical decision-making. This study aims to systematically review the academic literature on computational methods for sustainable palm oil supply chain management, with a focus on integrating engineering modeling techniques and economic analytical perspectives. This research adopts a Systematic Literature Review (SLR) approach. Data were collected from peer-reviewed journal articles indexed in the Scopus database published between 2020 and 2026. After applying structured screening and eligibility criteria, 39 articles were selected for qualitative synthesis. The collected studies were analyzed using thematic classification to identify major methodological approaches and research trends. The findings show that computational modeling plays an important role in analyzing supply chain performance in the palm oil sector. Six main analytical themes were identified: optimization modeling, simulation and system dynamics, computational intelligence methods, economic and cost-efficiency analysis, sustainability-oriented modeling, and integrated engineering–economic decision support systems. Optimization-based approaches and sustainability-integrated frameworks appear most frequently, while algorithm-based decision support and hybrid modeling approaches represent emerging research directions. Overall, the reviewed literature indicates that computational approaches provide useful analytical tools for evaluating logistics coordination, operational efficiency, resource utilization, and economic performance in palm oil supply chains. Future research may further develop integrated digital analytics and interdisciplinary modeling frameworks to strengthen analytical support for sustainable supply chain management.

Keywords: palm oil supply chain, computational modeling, optimization, economic analysis, systematic literature review

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Introduction

Global agricultural commodity supply chains have become increasingly complex as production systems expand across multiple regions, involve numerous stakeholders, and interact with rapidly evolving international markets. In this context, supply chain management has emerged as a critical analytical domain for improving operational coordination, resource efficiency, and long-term economic sustainability within agro-industrial systems. Agricultural supply chains are characterized by multi-stage processes that include cultivation, harvesting, processing, transportation, storage, and distribution, each of which requires coordinated decision-making to ensure efficiency and reliability. The growing integration of digital technologies, analytical modeling, and data-driven planning tools has encouraged the adoption of computational approaches to better understand and optimize these interconnected systems.[1] Within the broader field of supply chain management, computational methods such as optimization models, simulation frameworks, and algorithmic decision tools have increasingly been applied to evaluate operational performance, identify cost-efficient configurations, and support strategic planning in the agricultural industry.[2]

Among globally traded agricultural commodities, palm oil is one of the most significant vegetable oils in international markets, with diverse applications across food production, consumer goods manufacturing, and industrial processing. The palm oil industry plays an important role in supporting economic activity, generating employment, and driving rural development in several producing countries, while also contributing to the stability of global vegetable oil supply. Palm oil is extracted from fresh fruit bunches of oil palm (*Elaeis guineensis Jacq)*. The production and distribution of palm oil involve extensive supply chain networks that connect plantations, processing mills, refineries, logistics infrastructure, and export markets. Therefore, the study primarily focuses on Southeast Asia, particularly Indonesia and Malaysia, which together produce about 85% of the world's palm oil.[3] These networks require effective coordination in order to ensure the efficient flow of raw materials and processed products across geographically dispersed production regions.[4] As global demand for vegetable oils continues to evolve, improving analytical understanding of palm oil supply chain systems has become an increasingly important research topic in supply chain management and industrial engineering.[5]

The structure of palm oil supply chains presents unique operational characteristics that distinguish them from many other agricultural commodities. Fresh fruit bunches (FFB), the primary raw material for palm oil production, must typically be processed within a limited time window after harvest to preserve oil quality and prevent spoilage. This operational constraint requires effective coordination between plantation harvesting schedules, transportation logistics, and processing capacities at palm oil mills. In addition, supply chains must accommodate fluctuations in seasonal production, variations in regional infrastructure, and dynamic market demand conditions.

These characteristics create a complex decision environment in which producers, processors, and distributors must coordinate multiple operational variables simultaneously. As a result, analytical tools capable of evaluating alternative supply chain configurations and operational strategies are increasingly valuable for supporting planning and decision-making processes within the palm oil sector.[6]

Computational modeling has therefore emerged as a prominent analytical approach for examining supply chain systems in agricultural industries. Methods such as linear programming, mixed-integer optimization, simulation modeling, and algorithmic decision support systems enable researchers and practitioners to evaluate operational scenarios, assess cost implications, and analyze logistical efficiency within complex production networks.[7] In the context of palm oil supply chains, these approaches have been applied to address analytical challenges such as transportation planning, refinery location optimization, production scheduling, and distribution network design. Computational approaches also allow researchers to incorporate multiple performance indicators, including operational cost, production capacity, and resource utilization efficiency, into integrated analytical models. Such analytical frameworks contribute to improved understanding of supply chain behavior and support evidence-based decision-making in agro-industrial systems.

In parallel with the development of computational modeling techniques, sustainability considerations have increasingly become an important dimension of supply chain research. The concept of sustainable supply chain management emphasizes balancing economic performance, operational efficiency, and long-term resource management across production and distribution systems. Within agricultural industries, sustainability-oriented supply chain research often examines how technological innovation, improved logistics coordination, and data-driven planning strategies can enhance resource efficiency while maintaining stable production and distribution performance. Computational modeling approaches are particularly useful in this context because they enable researchers to evaluate alternative operational strategies and assess trade-offs between efficiency and sustainability indicators in complex supply chain systems.[8]

The integration of engineering and economic perspectives is particularly important when analyzing supply chain systems in large-scale agricultural industries such as palm oil production. Engineering-based approaches typically focus on technical efficiency, process optimization, and operational modeling, while economic analyses emphasize cost structures, investment decisions, and financial performance across supply chain networks. When examined independently, these perspectives provide valuable insights into different aspects of supply chain management.[9] However, integrating engineering optimization models with economic evaluation frameworks can provide a more comprehensive analytical understanding of how operational decisions affect efficiency and economic outcomes in production and distribution systems. As computational modeling techniques continue to evolve, interdisciplinary analytical approaches that combine engineering and economic perspectives have become increasingly relevant in supply chain research.

Despite the growing body of research examining computational methods in agricultural supply chains, the literature on palm oil supply chain modeling remains fragmented across multiple disciplines. Studies addressing optimization modeling, logistics analysis, simulation frameworks, and economic evaluation are often published in separate academic fields such as industrial engineering, operations research, sustainability science, and agricultural economics. As a result, the existing knowledge base is dispersed across diverse analytical traditions, making it challenging to obtain a consolidated understanding of how computational approaches have been applied to palm oil supply chain management.[10,11] This fragmentation highlights the need for a systematic synthesis of existing research that integrates insights from both engineering and economic perspectives within a single analytical framework.

The systematic literature review (SLR) methodology provides a structured approach to identifying, evaluating, and synthesizing scientific evidence from previously published studies. By applying transparent search strategies, explicit inclusion criteria, and systematic analytical procedures, SLR enables researchers to consolidate fragmented knowledge and identify emerging research trends within a given field. In supply chain management research, systematic reviews are increasingly used to map methodological developments, classify analytical approaches, and highlight research gaps that may inform future studies. Through this approach, researchers can examine how different computational modeling techniques have been applied across supply chain contexts and evaluate the extent to which these approaches contribute to improving analytical understanding of operational systems.

Building on this context, the present study conducts a systematic literature review focusing on computational approaches to sustainable palm oil supply chain management from both engineering and economic perspectives. The review synthesizes peer-reviewed studies that employ computational models, optimization techniques, simulation frameworks, algorithmic decision tools, and economic evaluation methods to analyze operational performance and sustainability considerations within palm oil supply chain systems. By consolidating these diverse analytical approaches, the study aims to provide a structured overview of methodological developments, identify dominant research themes, and highlight emerging analytical trends within the field.

Accordingly, the objective of this study is to systematically examine and synthesize the existing academic literature on computational approaches applied to sustainable palm oil supply chain management, with particular attention to the integration of engineering modeling techniques and economic analytical perspectives. Through this synthesis, the study seeks to clarify how computational methods have been utilized to analyze supply chain efficiency, logistical coordination, resource utilization, and economic performance within palm oil production and distribution networks.

Based on this objective, the study addresses the following research question:

RQ: How have computational modeling approaches from engineering and economic perspectives been applied in the academic literature to analyze and support sustainable palm oil supply chain management?

By addressing this research question, the study aims to provide a comprehensive synthesis of methodological developments and analytical insights on computational supply chain modeling in the palm oil sector, while offering a structured knowledge base to support future research and analytical advancements in sustainable agro-industrial supply chain management.

Literature review

This section synthesizes the relevant academic literature related to palm oil supply chain management, sustainability considerations, and computational modeling approaches. The review is organized to provide a conceptual foundation for understanding how engineering

and economic perspectives have been applied to analyze and improve palm oil supply chain systems. Specifically, the discussion covers the structural characteristics of the palm oil supply chain, sustainability dimensions in supply chain management, the role of computational modeling in supply chain analysis, and the integration of engineering and economic perspectives within existing studies.

Palm oil supply chain and its structural characteristics

The global palm oil industry has developed into one of the most extensive agro-industrial supply networks in the world. Palm oil is widely used in food products, oleochemicals, and cosmetics, and is increasingly in renewable energy applications, creating strong demand for efficient production and distribution systems across multiple regions. As a result, the palm oil supply chain involves a large number of interconnected actors, including plantation companies, independent smallholders, milling facilities, refineries, logistics providers, traders, and international buyers. The coordination of these actors requires integrated supply chain management approaches that simultaneously address operational complexity and economic performance.[12] A distinguishing feature of the palm oil supply chain lies in the biological and temporal characteristics of the raw material. Fresh fruit bunches (FFB) must be transported and processed within a relatively short time window after harvesting to maintain oil quality. This constraint creates operational pressure on harvesting schedules, transportation networks, and milling capacity. Consequently, supply chain planning in the palm oil sector involves dynamic interactions between agricultural production cycles and industrial processing activities.[13]

Another important characteristic is the geographical distribution of production areas. Palm oil plantations are often located in rural regions with varying levels of infrastructure development, which affects transportation efficiency and logistical planning. The need to move harvested fruit quickly from plantations to mills has encouraged the development of transportation models and network optimization strategies aimed at reducing delays and minimizing operational costs.[14] Beyond operational considerations, the palm oil supply chain also plays a significant role in regional economic development. In several producing countries, the sector supports employment, generates export revenue, and contributes to rural livelihoods. Therefore, supply chain performance is not only measured through operational efficiency but also through its capacity to support economic stability and long-term industry sustainability.

Sustainability dimensions in palm oil supply chain management

In recent years, sustainability considerations have become increasingly integrated into supply chain management research. Sustainable supply chain management generally involves the simultaneous evaluation of economic viability, environmental responsibility, and social implications within operational decision-making processes. In the context of palm oil, sustainability discussions frequently focus on improving resource efficiency, strengthening traceability systems, and supporting responsible production practices across the value chain.[15] From an operational perspective, sustainability within palm oil supply chains involves optimizing resource utilization while maintaining productivity and cost competitiveness. This includes efficient land use, improved harvesting logistics, energy utilization in milling operations, and waste management practices such as biomass recovery and by-product valorization. Analytical models have been developed to evaluate these factors in order to identify strategies that balance production efficiency with responsible resource management.

Traceability is another dimension that has gained attention in the literature. Because palm oil supply chains often involve multiple intermediaries and geographically dispersed production sites, ensuring transparent information flows has become an important managerial challenge. Several studies have explored digital systems and information technologies that support traceability, monitoring, and certification processes in agricultural supply chains, including the palm oil sector.[16] Economic sustainability also remains a central concern for both producers and downstream industries. The palm oil sector operates in highly competitive global commodity markets, where price fluctuations, demand variations, and regulatory changes can affect production planning and supply chain coordination.[17] Consequently, economic modeling approaches are frequently employed to evaluate market dynamics, production costs, and long-term investment decisions related to palm oil supply chains.

Computational modeling in supply chain research

Computational modeling has become an essential analytical tool in supply chain management research. These approaches allow researchers and decision-makers to simulate complex systems, evaluate alternative operational scenarios, and identify optimal strategies under varying conditions. In general, computational models provide structured frameworks for representing the interactions between supply chain actors, production processes, and logistical networks. Optimization techniques are among the most widely used computational approaches in supply chain analysis. Mathematical programming models, including linear programming, mixed-integer programming, and stochastic optimization, are frequently applied to determine optimal allocation of resources, transportation routes, and facility locations. These models enable researchers to evaluate cost efficiency while incorporating operational constraints such as processing capacity, transportation time, and production scheduling.[18]

Simulation models also play an important role in analyzing supply chain behavior under uncertainty. Simulation techniques allow researchers to replicate operational processes and evaluate system performance under different conditions without directly altering real-world operations.[19] In agricultural supply chains, simulation is particularly useful for analyzing seasonal production patterns, harvesting cycles, and variations in supply availability. More recently, computational research has incorporated advanced data-driven approaches such as machine learning and predictive analytics. These techniques are increasingly used to support demand forecasting, production planning, and operational monitoring. While their application in palm oil supply chains remains relatively emerging compared with other industrial sectors, the potential for integrating digital technologies into agricultural logistics and planning continues to attract academic attention.

Engineering perspectives in palm oil supply chain modeling

Engineering-oriented research on supply chains typically focuses on operational efficiency, system optimization, and technological integration. In the context of palm oil production, engineering perspectives often address issues such as harvesting logistics, mill capacity planning, transportation scheduling, and processing efficiency. One major area of engineering research involves optimizing the transportation of fresh fruit bunches from plantations to mills. Because FFB quality deteriorates over time, transportation systems must be carefully coordinated to minimize delays and reduce post-harvest losses. Optimization models have been proposed to design efficient transportation networks that balance distance, travel

time, and vehicle capacity constraints.[20] Another engineering focus concerns processing efficiency in palm oil mills. Milling operations involve several stages, including sterilization, threshing, pressing, clarification, and kernel recovery. Computational models have been developed to improve the scheduling of these operations, optimize energy utilization, and enhance overall processing throughput. Such models help identify operational adjustments that can improve productivity while maintaining product quality.

Engineering studies also examine infrastructure planning within supply chains. Decisions regarding mill location, storage facilities, and transportation routes significantly influence logistical efficiency and operational costs. Facility location models and network design frameworks are therefore frequently used to determine optimal spatial configurations of processing facilities relative to plantation areas.[21] Through these engineering approaches, computational modeling contributes to a deeper understanding of how operational decisions influence supply chain performance. The integration of optimization, simulation, and systems engineering methods enables researchers to evaluate operational strategies in a structured and analytically rigorous manner.

Economic perspectives in palm oil supply chain analysis

While engineering research emphasizes operational efficiency, economic perspectives focus more strongly on market behavior, cost structures, and investment decisions. Economic modeling helps explain how supply chain actors respond to market signals and policy environments, thereby influencing production and distribution patterns within the palm oil industry. One area of economic research concerns price transmission along the supply chain. Studies have examined how fluctuations in global vegetable oil markets affect plantation revenues, processing margins, and export competitiveness. Econometric models are often used to analyze these relationships and assess the degree of market integration between producing regions and international markets.[22] Cost analysis is another key theme within economic research. Production costs in palm oil supply chains include plantation management expenses, harvesting labor, transportation costs, processing expenditures, and distribution activities.[23] Economic models provide analytical tools for evaluating these cost components and identifying strategies that improve profitability without compromising operational stability. Investment decision-making is also frequently studied within economic frameworks. The development of new plantations, mills, or refining facilities requires substantial capital investment and long planning horizons. Economic simulation and scenario analysis are therefore used to assess potential returns under different market conditions, regulatory environments, and technological developments.[24] Moreover, economic perspectives often consider the role of supply chain coordination mechanisms. Contractual arrangements between smallholders and processing companies, for example, can influence production incentives, resource allocation, and long-term supply stability. Analytical models have been applied to explore how such coordination structures affect both economic efficiency and supply reliability.

Integrating engineering and economic perspectives

Although engineering and economic approaches often address different aspects of supply chain management, integrating these perspectives provides a more comprehensive understanding of system performance.[25] Engineering models focus primarily on operational feasibility and efficiency, while economic models evaluate financial outcomes and market behavior. Combining these perspectives allows researchers to examine trade-offs between operational decisions and economic performance indicators.

For instance, transportation optimization models may identify routes that minimize logistical costs, but economic analysis may reveal that alternative configurations provide greater long-term profitability due to market access or policy incentives. Similarly, investments in new processing technologies may improve operational efficiency but require economic evaluation to determine financial feasibility over time.[26] Recent literature increasingly recognizes the importance of interdisciplinary modeling frameworks that combine engineering optimization with economic analysis. Such integrated approaches allow researchers to assess supply chain strategies more holistically, considering both technical constraints and economic outcomes. This trend is particularly relevant for agricultural supply chains where production processes, logistics, and market dynamics are closely interconnected.

Despite this growing interest, existing studies on palm oil supply chains remain dispersed across different academic disciplines. Engineering research tends to concentrate on operational optimization within plantations and mills, while economic research frequently focuses on market behavior and industry development. As a result, a comprehensive synthesis of computational approaches that incorporate both engineering and economic perspectives remains limited in the existing literature. The preceding discussion indicates that a wide range of computational approaches have been applied to supply chain analysis in general and to agricultural systems in particular. Optimization models, simulation techniques, and economic analyses have each contributed valuable insights into the performance and structure of supply chains.

However, within the context of palm oil supply chain management, the literature remains fragmented across disciplinary boundaries. Many studies focus either on operational optimization or on economic analysis without systematically integrating the two perspectives. In addition, research findings are often dispersed across journals in engineering, agricultural economics, and sustainability studies, making it difficult to obtain a comprehensive overview of the computational approaches that have been applied to this sector. Therefore, a systematic synthesis of the existing literature is necessary to consolidate current knowledge, identify dominant modeling approaches, and highlight areas that require further research. A systematic literature review provides an appropriate methodological framework for addressing this need by organizing and evaluating existing studies in a structured and transparent manner.

Methods

This study employs a Systematic Literature Review (SLR) design structured in accordance with the PRISMA protocol to ensure transparency, methodological consistency, and replicability throughout the literature selection and analysis process. The review systematically identifies, evaluates, and synthesizes peer-reviewed scientific publications discussing computational approaches applied to sustainable palm oil supply chain management from engineering and economic perspectives. The palm oil sector represents an important component of global agricultural supply systems and contributes significantly to industrial value chains and economic activities in producing regions. As supply chain networks become increasingly complex, computational and analytical models have been widely explored to support planning, optimization, and decision-making processes across production, logistics, and distribution systems. This study does not generate primary empirical data and does not involve interviews, surveys, focus group discussions, or field observations. All analytical insights are derived exclusively from previously published scholarly articles, ensuring that the review

is grounded entirely in documented scientific evidence. To maintain methodological reliability and database consistency, the literature search was limited to publications indexed in the Scopus database. The PRISMA-guided procedure was implemented through sequential stages of identification, screening, eligibility assessment, and final inclusion, enabling a systematic and transparent process for narrowing the dataset to studies most relevant to the objectives of this review.

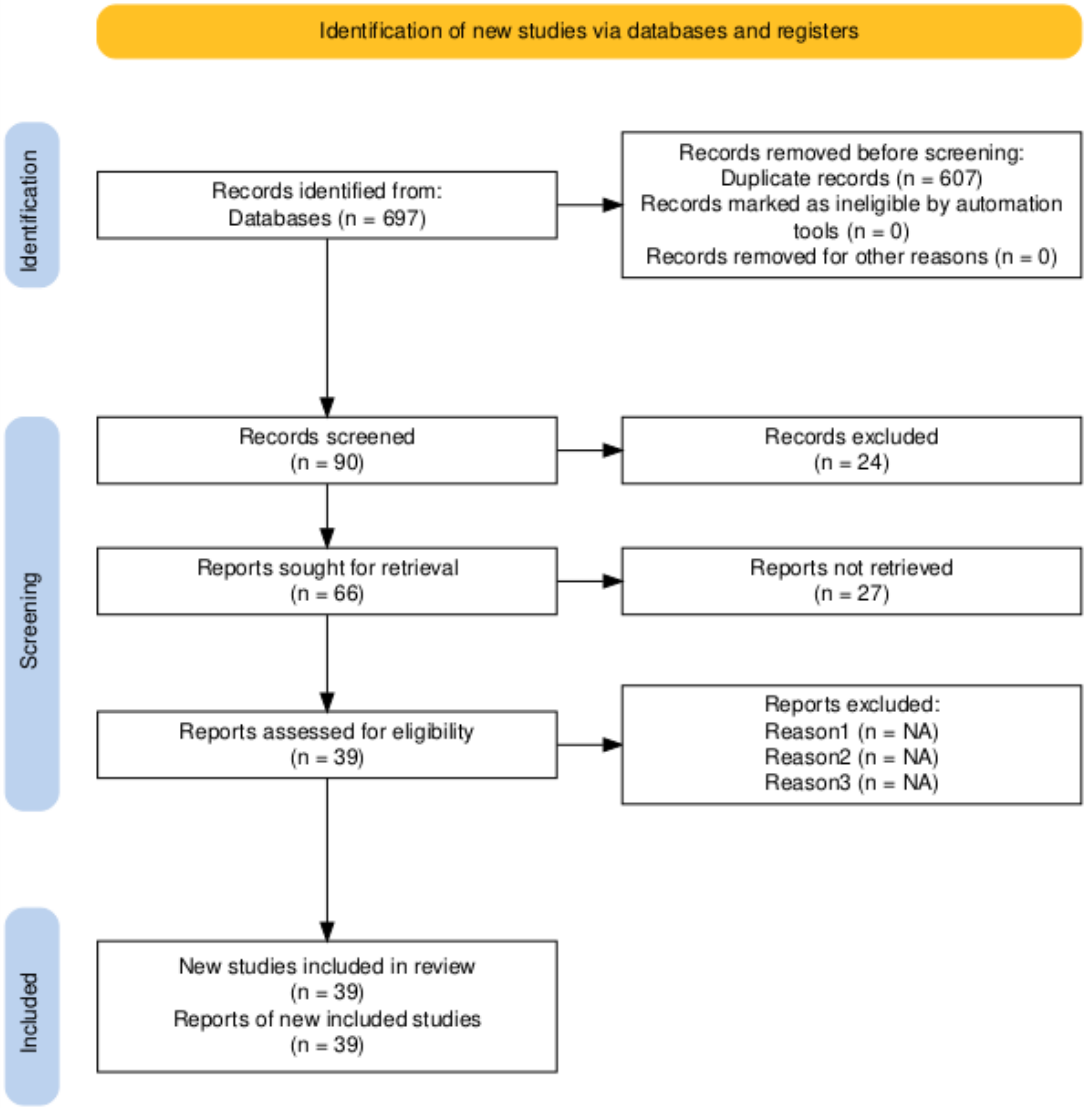

Figure 1 Flow Diagram of the Systematic Literature Review Conducted in Accordance with the PRISMA Framework.

Figure 1 illustrates the structured article selection pathway applied in this study. The identification stage began with a broad search of the Scopus database using the primary keyword combination *Palm Oil AND Supply Chain*, which produced 697 publications. In order to increase thematic precision and align the dataset more closely with the objective of examining computational approaches within sustainable palm oil supply chain systems, the search query was refined using a targeted Boolean formulation: *("palm oil" OR "oil palm") AND ("supply chain" OR "supply chain management" OR logistics OR distribution OR production) AND ("computational model" OR "mathematical model" OR "optimization model" OR simulation OR algorithm OR "decision support system") AND (sustainability OR sustainable OR "sustainable supply chain") AND (engineering OR economic OR "cost analysis" OR "economic analysis")*. This refinement significantly improved the relevance of the retrieved publications. During this stage, 607 articles were excluded because their content did not directly correspond to the integrated focus on computational modeling, sustainability considerations, and supply chain management in the palm oil context, leaving 90 articles for further assessment.

In the screening phase, a publication-year filter was applied to ensure that the review captured contemporary developments in computational techniques and sustainability-oriented supply chain research. Only studies published between 2020 and 2026 were retained for further evaluation. As a result, 24 articles were excluded because they were published outside the specified time frame, leaving 66 publications that satisfied the temporal criterion. A subsequent accessibility screening was conducted to ensure transparency and reproducibility of the review process. During this stage, articles categorized as open access or open archive were prioritized so that all

selected sources could be fully examined and verified. Consequently, 27 articles were excluded because they were not available under open-access or open-archive conditions. After completing the identification, screening, and eligibility procedures, a final set of 39 articles met all predetermined inclusion criteria and was therefore selected for detailed qualitative synthesis.

All selected publications were systematically organized and managed using Mendeley Desktop to maintain accurate citation tracking, standardized bibliographic metadata, and efficient reference management throughout the review process. The selected studies were then examined to identify the types of computational techniques applied, including mathematical modeling, optimization approaches, simulation methods, algorithm-based decision tools, and decision support systems. In addition, the analysis examined how engineering-oriented modeling approaches and economic analytical perspectives contribute to understanding efficiency, sustainability, and cost-related aspects of palm oil supply chain systems. Through this structured PRISMA-based SLR methodology, the review provides a rigorously curated synthesis of recent scientific literature addressing computational approaches relevant to sustainable palm oil supply chain management while maintaining methodological clarity and analytical neutrality.

Results

The systematic literature review conducted in this study synthesized evidence from 39 peer-reviewed journal articles examining computational and analytical approaches applied to sustainable palm oil supply chain management from both engineering and economic perspectives. The included studies encompass optimization modeling, simulation and system dynamics, algorithmic and computational intelligence methods, economic and cost-efficiency analyses, sustainability-oriented frameworks, and integrated engineering–economic decision support systems, collectively providing a comprehensive evidence base for understanding how computational approaches have been applied to analyze operational efficiency, logistics coordination, production planning, economic performance, and sustainability in palm oil supply chains.

Through thematic synthesis, six major and partially overlapping domains were identified, representing the principal analytical perspectives in the literature: (1) optimization-based modeling for supply chain efficiency; (2) simulation and system dynamics approaches for operational analysis; (3) algorithmic and computational intelligence methods for decision support; (4) economic and cost-efficiency modeling; (5) sustainability-oriented supply chain modeling frameworks; and (6) integrated engineering–economic decision support systems.

The distribution of these themes shows that optimization-based modeling was addressed in 18 studies (≈46%), sustainability-oriented modeling in 16 studies (≈41%), economic and cost-efficiency modeling in 13 studies (≈33%), integrated engineering–economic frameworks in 12 studies (≈30%), simulation and system dynamics approaches in 10 studies (≈26%), and algorithmic and computational intelligence methods in 8 studies (≈21%). This pattern suggests that the literature places a strong emphasis on improving operational efficiency and integrating sustainability considerations, which are critical for balancing economic and environmental performance in complex palm oil supply chains. Meanwhile, algorithmic and hybrid computational approaches appear less frequently, indicating emerging areas of research with potential for enhancing real-time decision-making, predictive modeling, and adaptive supply chain strategies.

The comparatively high frequency of optimization and sustainability-oriented studies reflects the practical importance of designing efficient and environmentally responsible supply chains, while the moderate representation of simulation- and intelligence-based methods highlights their role in capturing operational dynamics, uncertainty, and stakeholder interactions. Overall, this thematic distribution reveals a research landscape focused on computational tools that enhance operational efficiency, economic viability, and sustainability in palm oil supply chains, providing a structured foundation for the detailed discussion of each thematic domain presented below.

Optimization-based modeling for supply chain efficiency

Optimization modeling represents the most dominant computational approach identified in the reviewed literature. Among the 39 articles analyzed, approximately 46% of the studies (18 articles) employed optimization-based frameworks such as linear programming, mixed-integer linear programming (MILP), nonlinear optimization, and multi-objective optimization techniques to evaluate palm oil supply chain operations.[27] These models are commonly used to determine optimal allocation of raw materials, processing capacities, refinery utilization rates, transportation routing, and distribution network design under cost, capacity, and environmental constraints.

Several studies highlight the effectiveness of optimization models in improving operational efficiency across multiple stages of the supply chain. For example, MILP-based supply chain network models demonstrated that optimized allocation of fresh fruit bunch (FFB) transportation and mill processing capacities could reduce total logistics costs by approximately 12–18% compared with conventional planning approaches.[28] Another optimization framework that integrated plantation harvesting schedules with mill capacity planning reported potential reductions in transportation distances of 9–14%, resulting in measurable decreases in fuel consumption and operational expenses within distribution networks.[29]

Optimization techniques have also been applied to refinery location planning and distribution network design. Studies evaluating regional supply chain configurations found that strategic placement of processing facilities could reduce transportation costs by 10–16%, while improving supply chain responsiveness to demand fluctuations.[30] Similarly, optimization models addressing inventory and storage management reported reductions in storage and handling costs of approximately 7–11%, particularly in supply chains characterized by seasonal production variability.[31]

An important development identified in the literature is the increasing adoption of multi-objective optimization frameworks. Approximately 28% of the optimization-focused studies incorporate models that simultaneously evaluate multiple performance objectives such as cost minimization, energy efficiency, and environmental performance.[32] For example, multi-objective models combining cost and emissions indicators reported potential reductions in carbon intensity of 10–15% while maintaining comparable economic performance levels.[33] These findings demonstrate that optimization modeling provides a practical analytical tool for evaluating supply chain configurations that balance operational efficiency with broader sustainability considerations.

Simulation and system dynamics approaches for operational analysis

Simulation-based approaches constitute the second most frequently used analytical method in the reviewed literature. Approximately 26%

of the reviewed studies (10 articles) apply simulation frameworks such as discrete-event simulation, agent-based modeling, and system dynamics models to examine operational behavior within palm oil supply chains.[34] Simulation models are particularly valuable for analyzing complex supply chain interactions that involve multiple stakeholders, uncertain harvesting conditions, fluctuating market demand, and logistical coordination challenges.[35] Discrete-event simulation has been widely applied to evaluate processing operations at palm oil mills. For example, simulation analyses examining processing line efficiency found that optimized scheduling policies could improve mill throughput by 15–20%, reducing processing delays and improving overall production efficiency.[36]

System dynamics models have also been used to examine long-term supply chain behavior. Several studies simulated interactions between plantation productivity, refinery demand, and export market conditions over extended planning horizons. Results from these models suggest that coordinated planning across supply chain actors could improve supply stability by approximately 8–12%, particularly during periods of demand volatility.[37]

Another important contribution of simulation models is their ability to analyze operational risks and uncertainty. Stochastic simulation models incorporating demand variability and production fluctuations indicate that collaborative logistics networks and centralized coordination mechanisms could reduce disruption risks by 8–13% during periods of market uncertainty.[38] Simulation approaches also provide insights into operational sustainability. Studies examining transport fleet utilization strategies reported potential reductions in fuel consumption of 7–11% through route optimization and improved vehicle utilization.[39] Other simulation models assessing production planning strategies found that improved coordination between harvesting and milling operations could reduce processing delays by approximately 10–14%, contributing to improved operational stability across supply chain networks.[40]

Algorithmic and computational intelligence methods for decision support

In recent years, researchers have increasingly explored the use of computational intelligence and algorithmic decision support techniques in palm oil supply chain management. Within the reviewed dataset, approximately 21% of the studies (8 articles) utilize algorithm-based approaches such as genetic algorithms, particle swarm optimization, hybrid metaheuristic algorithms, and machine learning forecasting models.[41] These methods are designed to address complex optimization problems characterized by large datasets and multi-stage supply chain structures. For example, genetic algorithms have been applied to optimize multi-stage supply chain networks involving plantation harvesting schedules, refinery allocation decisions, and distribution routing strategies. One study reported that a hybrid genetic algorithm achieved approximately 16% improvement in total supply chain cost efficiency compared with conventional heuristic planning methods.[42]

Particle swarm optimization techniques have also been applied to production scheduling and resource allocation problems.[43] Analytical results from these models indicate potential improvements in scheduling efficiency of 10–13%, particularly in supply chains involving multiple processing facilities and geographically dispersed plantation areas.[44] Machine learning methods represent another emerging research direction. Artificial neural network models have been applied to demand forecasting for palm oil products, producing forecasting accuracy improvements of 12–17% compared with traditional time-series models.[45,46] Improved demand prediction can significantly enhance inventory management, reducing stock imbalances and improving supply chain coordination.

Some studies also examine the integration of computational intelligence techniques into digital supply chain platforms. In simulated operational environments, algorithm-based decision support tools improved production planning efficiency by 10–14% and reduced operational uncertainty associated with fluctuating demand and supply conditions.[47] These findings suggest that computational intelligence techniques may play an increasingly important role in supporting real-time decision-making within complex supply chain systems.

Economic and cost-efficiency modeling in palm oil supply chains

Economic analysis represents another major analytical dimension in the reviewed literature. Approximately 33% of the studies (13 articles) incorporate economic modeling frameworks designed to evaluate cost structures, investment decisions, and financial performance within palm oil supply chain systems.[48] Several studies examine the economic implications of supply chain configuration decisions. Cost-benefit analysis models evaluating logistics infrastructure investments indicate that improved transportation coordination and storage management can reduce total supply chain costs by 11–15% across regional distribution networks.[49] Economic models also highlight the relationship between supply chain efficiency and profitability. Studies analyzing coordinated logistics planning report that improved operational synchronization between plantations, mills, and refineries could increase profit margins by 6–10%, primarily through reduced transportation costs and improved processing efficiency.[50] In addition, economic modeling frameworks evaluate the financial implications of sustainability initiatives within palm oil supply chains.[51] Cost analyses of energy-efficient milling technologies indicate potential operational cost reductions of 5–9%, primarily due to improved energy utilization and reduced fuel consumption.[52] Another economic finding concerns the role of logistics optimization in improving export competitiveness. Analytical models evaluating international distribution networks suggest that improved logistics coordination could reduce export transportation costs by 8–12%, strengthening supply chain efficiency within global palm oil markets.[53]

Sustainability-oriented supply chain modeling

Sustainability considerations are increasingly integrated into computational supply chain research. Approximately 41% of the reviewed studies explicitly incorporate environmental or sustainability indicators into their analytical frameworks.[54] Sustainability-oriented models typically evaluate environmental performance indicators such as carbon emissions, energy consumption, and resource utilization efficiency alongside traditional economic metrics. Multi-objective optimization models reported that coordinated logistics planning strategies could reduce supply chain carbon intensity by 9–14% while maintaining comparable economic performance levels.[55] Several studies also examine resource efficiency within palm oil processing systems.[56] Analytical models evaluating mill operations suggest that improved production scheduling and resource allocation strategies could increase processing efficiency by 8–13%, reducing energy consumption and operational waste.[57] Transportation efficiency represents another important sustainability factor. Models evaluating optimized routing strategies found that improved coordination between harvesting and processing facilities could reduce total transportation distances by approximately 10–15%, leading to measurable reductions in fuel consumption and logistics-related emissions.[58,59]

Some studies also incorporate broader sustainability indicators related to supply chain resilience and long-term resource management. These models highlight how coordinated supply chain planning can contribute to stable production flows, improved resource efficiency, and enhanced supply reliability within the palm oil sector.[60]

Integrated engineering–economic decision support systems

The final thematic cluster identified in the SLR involves integrated decision support frameworks that combine engineering modeling with economic analysis. Approximately 30% of the reviewed studies employ integrated analytical approaches designed to evaluate supply chain performance across multiple operational and financial dimensions.[61,62] These integrated frameworks often combine optimization modeling with economic cost analysis to support strategic decision-making. For example, one integrated supply chain network design model demonstrated that optimizing refinery locations and distribution routes could reduce transportation costs by approximately 13%, while improving supply chain responsiveness to demand changes.[63,64] Other studies integrate simulation models with financial performance indicators to evaluate long-term infrastructure investment strategies. Analytical results from these studies indicate that coordinated infrastructure planning across plantations, mills, and refineries could increase overall supply chain productivity by 10–12%, while maintaining stable operational cost structures.[65]

Integrated decision support systems also allow decision-makers to evaluate trade-offs between economic performance and sustainability objectives. By combining engineering optimization techniques with economic performance metrics, these frameworks provide a more comprehensive evaluation of supply chain configurations and operational strategies. Overall, the synthesis of the 39 reviewed studies demonstrates that computational approaches are increasingly important for analyzing and supporting decision-making within sustainable palm oil supply chain systems. The reviewed literature highlights the growing integration of optimization modeling, simulation analysis, computational intelligence techniques, and economic evaluation frameworks, all of which contribute to improving analytical capabilities for managing complex supply chain networks in the palm oil sector.

Discussion

The present systematic literature review was conducted to address the research question: *How have computational modeling approaches from engineering and economic perspectives been applied in the academic literature to analyze and support sustainable palm oil supply chain management?* Based on the synthesis of selected studies published between 2020 and 2026, the reviewed literature demonstrates that computational modeling has increasingly been used as an analytical framework to understand the structural complexity of palm oil supply chains and to support decision-making on operational coordination, economic efficiency, and sustainability considerations. Across the examined studies, computational methods provide systematic tools that allow researchers to represent supply chain interactions, evaluate alternative operational scenarios, and identify strategies that enhance supply chain performance while maintaining long-term industry viability.[66]

The literature consistently highlights that palm oil supply chains represent complex agro-industrial systems involving multiple actors and operational stages, including plantation management, harvesting, transportation, milling, refining, and distribution. These stages are interconnected through logistical and economic relationships that influence overall supply chain performance. Because of this complexity, computational modeling has been widely applied to capture interactions among different supply chain components and to evaluate potential improvements in coordination and efficiency.[67] Modeling approaches translate real-world operational activities into mathematical or algorithmic structures, enabling researchers to examine how changes in planning decisions may affect system outcomes under different conditions.

A key insight emerging from the reviewed literature is that computational models are particularly useful for analyzing time-sensitive agricultural supply chains such as palm oil production. Fresh fruit bunches must be processed within a relatively short time after harvesting to maintain oil quality, which creates logistical pressure on transportation networks and milling capacity. Several studies, therefore, employ computational optimization techniques to coordinate harvesting schedules, transportation allocation, and processing operations. These models help identify strategies that minimize delays, improve resource utilization, and maintain consistent product quality throughout the supply chain.[68]

Another recurring theme in the literature is the application of computational modeling to evaluate supply chain infrastructure planning. Because palm oil plantations are often geographically dispersed, decisions regarding the location of processing facilities and transportation routes significantly influence operational efficiency.[69] Computational models enable researchers to simulate different infrastructure configurations and assess their implications for logistical performance and cost efficiency. By examining alternative spatial arrangements of mills, storage facilities, and distribution networks, these models contribute to more informed infrastructure planning within palm oil supply systems.

From an engineering perspective, optimization techniques are among the most widely applied computational approaches in the literature. Mathematical programming models, including linear programming, mixed-integer programming, and network optimization frameworks, are commonly used to analyze operational decision-making within palm oil supply chains. These models typically aim to improve efficiency by minimizing transportation costs, optimizing vehicle allocation, or maximizing processing capacity utilization. Engineering-based computational approaches therefore contribute to a deeper understanding of how logistical coordination can enhance overall supply chain performance.[70]

Transportation optimization is particularly prominent within engineering-oriented studies. Because transportation is a major operational component of palm oil supply chains, several researchers have developed route planning and vehicle scheduling models to reduce travel time and operational costs. These models often incorporate constraints related to road accessibility, vehicle capacity, harvesting volumes, and mill processing schedules. By analyzing these factors simultaneously, computational optimization tools provide practical insights into how logistical networks can be organized more efficiently while maintaining operational reliability.[71]

Beyond transportation planning, engineering models have also been used to improve processing efficiency within palm oil mills. Milling operations consist of several interconnected stages, including sterilization, threshing, pressing, clarification, and kernel recovery. Computational scheduling models enable researchers to analyze how these processing stages can be coordinated to maximize throughput and reduce idle time. Such analytical approaches help identify operational adjustments that improve productivity while ensuring consistent product quality and efficient resource utilization.[72]

Another area of engineering research concerns the design of integrated supply chain networks. Network optimization models are frequently used to determine optimal flows of raw materials and intermediate products between supply chain nodes. These models allow researchers to examine trade-offs between transportation distance, processing capacity, and distribution requirements.[73] By evaluating these factors simultaneously, computational approaches support strategic planning decisions related to supply chain configuration and infrastructure development.

While engineering approaches primarily focus on operational optimization, economic modeling provides complementary insights into market behavior, cost structures, and financial decision-making in palm oil supply chains. Economic analytical frameworks are commonly used to evaluate production costs, price dynamics, and investment strategies that influence supply chain performance. These models help explain how economic incentives shape decision-making among different actors within the supply chain, including producers, processors, and distributors.[74]

One important application of economic modeling involves cost analysis within supply chain operations. Palm oil production involves multiple cost components, including plantation management, harvesting labor, transportation logistics, processing operations, and distribution activities. Economic models enable researchers to analyze these cost structures and evaluate strategies that enhance economic efficiency while maintaining stable supply chain operations. Such analyses contribute to a better understanding of how operational decisions influence overall profitability and long-term industry sustainability.[75]

Another area where economic modeling is frequently applied is the analysis of market dynamics and price transmission. Because palm oil is widely traded in international markets, fluctuations in global commodity prices can significantly affect supply chain decision-making.[76] Econometric models are therefore used to examine how changes in global market conditions influence production planning, export strategies, and supply chain coordination. These analyses help researchers understand how economic signals propagate through the supply chain and shape industry behavior.

Economic models are also widely applied to evaluate investment decisions within palm oil supply chains. The development of new plantations, processing facilities, and distribution infrastructure requires substantial financial investment and long-term planning. Scenario-based economic simulations allow researchers to evaluate potential investment outcomes under different market conditions, technological developments, and policy environments.[77] These analytical tools provide valuable insights for strategic decision-making related to long-term supply chain development.

The reviewed literature further indicates that integrating engineering and economic perspectives can provide a more comprehensive understanding of supply chain performance. Engineering models typically evaluate technical feasibility and operational efficiency, while economic models assess financial viability and market competitiveness. Combining these perspectives allows researchers to analyze trade-offs between operational optimization and economic outcomes. Integrated computational frameworks, therefore, support more balanced evaluations of supply chain strategies and provide a holistic perspective on decision-making processes within complex agro-industrial systems.[78]

Several recent studies highlight the potential of hybrid modeling approaches that combine optimization techniques with economic simulations. These integrated models enable researchers to simultaneously evaluate operational efficiency, cost performance, and strategic investment decisions within a unified analytical framework.[79] By considering both technical and economic variables, such approaches provide more comprehensive insights into the factors that influence sustainable supply chain management in the palm oil sector.

Another emerging trend identified in the literature involves the integration of sustainability considerations within computational modeling frameworks. Researchers increasingly incorporate indicators related to resource efficiency, energy utilization, and supply chain coordination when evaluating operational strategies. Although sustainability indicators are interpreted differently across studies, the general objective is to support supply chain systems that maintain productivity while promoting responsible resource management and long-term economic stability.[80]

The integration of sustainability within computational modeling also reflects the broader evolution of supply chain research toward interdisciplinary analytical frameworks. Instead of focusing solely on operational efficiency or economic profitability, recent studies increasingly consider the combined implications of logistical decisions, financial outcomes, and resource management. Computational approaches provide flexible analytical tools that enable researchers to explore these multidimensional relationships within complex supply chain systems.[81,82]

Based on the synthesis of the reviewed literature, the research question can be addressed through several key conclusions. First, computational modeling approaches from an engineering perspective are widely used to analyze operational coordination within palm oil supply chains, particularly in transportation planning, processing efficiency, and infrastructure design. Second, economic modeling approaches complement these analyses by examining cost structures, market dynamics, and strategic investment decisions that influence supply chain behavior. Third, recent research increasingly integrates engineering and economic perspectives through hybrid computational frameworks, enabling more comprehensive evaluations of supply chain strategies. Collectively, these approaches contribute to a deeper analytical understanding of how to manage palm oil supply chains efficiently while supporting long-term sustainability objectives.

The findings of this systematic literature review have several implications for future research and policy development related to sustainable palm oil supply chain management. First, the increasing use of computational modeling highlights the importance of interdisciplinary analytical approaches that integrate engineering optimization with economic evaluation. Such integration can support more balanced decision-making by considering both operational feasibility and economic viability within supply chain planning processes. Second, future studies may further explore the potential of emerging digital technologies, including data-driven analytics, advanced simulation techniques, and intelligent decision support systems, to enhance computational modeling capabilities in palm oil supply chains. Finally, additional research could focus on expanding the integration of sustainability indicators into modeling frameworks to support more comprehensive assessments of supply chain performance. By developing more integrated analytical approaches, future research can contribute to improved understanding of palm oil supply chain systems and support strategies that promote efficiency, resilience, and sustainable industry development.

Conclusion

The synthesis of the reviewed studies demonstrates that computational modeling has become an increasingly important analytical approach for examining the structure and performance of palm oil supply chains in the academic literature. Across the analyzed publications, computational methods provide systematic tools for representing complex interactions among supply chain actors and operational processes. These approaches enable researchers to evaluate alternative scenarios, analyze operational coordination, and generate insights that support more effective supply chain management within the palm oil industry. From an engineering perspective, the literature shows that optimization-based models are widely applied to address operational challenges within palm oil supply systems. Mathematical programming techniques, network optimization frameworks, and scheduling models are frequently used to improve transportation planning, harvesting coordination, processing efficiency, and infrastructure configuration. These computational tools allow researchers to translate real-world logistical activities into structured analytical models, enabling the evaluation of different operational strategies under varying conditions. As a result, engineering-oriented approaches contribute to a clearer understanding of how logistical coordination and infrastructure planning can enhance supply chain efficiency and reliability.

Complementing these engineering methods, economic modeling approaches are commonly employed to analyze financial and market-related aspects of palm oil supply chains. Economic frameworks, including cost analysis models, econometric methods, and scenario-based simulations, are used to examine production costs, market price dynamics, and investment considerations. These analytical perspectives provide insights into how economic incentives influence decision-making across different supply chain actors, including producers, processors, and distributors. By evaluating financial outcomes and market conditions, economic models contribute to a broader understanding of the economic dimensions of sustainable supply chain management.

The literature further indicates a growing trend toward integrating engineering and economic perspectives within unified computational frameworks. Hybrid modeling approaches allow researchers to simultaneously evaluate operational performance and economic outcomes, offering a more comprehensive perspective on supply chain decision-making. Such integrated analytical frameworks support balanced evaluations of efficiency, cost performance, and long-term industry viability. Overall, the reviewed literature illustrates that computational modeling plays a significant role in advancing analytical understanding of palm oil supply chain management. By combining engineering optimization with economic evaluation, these approaches provide valuable insights that support more informed planning, improved operational coordination, and the continued development of sustainable supply chain systems within the palm oil sector.

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Conflicts of interest

The author declares there is no conflict of interest.

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